



# Trans Forum<sup>TM</sup>

News From Argonne's Transportation Technology R&D Center

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## VIEWPOINT

### Reaping Rewards from 15 Years of Student Competitions

*FutureTruck and other DOE engineering competitions encourage innovations*

The FutureTruck 2002 college-level automotive engineering competition challenged student teams from 15 top North American universities to reengineer a conventional sport utility vehicle into a low-emissions vehicle with at least 25% higher fuel economy. The success of this competition and others like it is dramatic proof that the knowledge and effort invested in organizing student competitions to develop alternative fuel technologies can have an impact in the real world. *Page 2*

## RESEARCH REVIEW

### Fluid Dynamics Simulations Help Speed Fuel Processor Development

Argonne is working on developing a fuel processor suitable for light-duty vehicles. Design and integration of the fuel processing components are supported by computational fluid dynamics simulations that predict three-dimensional fluid flow, mixing, heat transfer, and chemical reactions inside each component of the fuel processor, as well as throughout the entire unit. *Page 4*

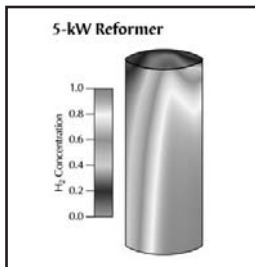
### Power Merger

*Seamlessly bonded ceramics provide new options for optimizing fuel cell electrodes*

The design of the flow field is one critical factor in extracting maximum power from a fuel cell unit. However, the use of complex flow fields drives up manufacturing costs. Argonne has demonstrated a new method that could provide a less expensive way to form complex shapes from conductive ceramics. The method forms a strong joint between two ceramic parts, while retaining all the electrical properties of the base material. *Page 5*

### New Bifunctional Catalysts Promise Dramatic NO<sub>x</sub> Reductions for Heavy-Duty Diesel Vehicles

The U.S. Environmental Protection Agency has ruled that a 95% cut in allowed nitrogen oxide (NO<sub>x</sub>) emissions will take effect in 2007. But the exhaust aftertreatment technology to meet that standard does not currently exist. Argonne researchers recently developed a series of bifunctional catalysts for use in aftertreatment devices that overcome all of the show-stopping drawbacks of other catalysts; they can operate at diesel exhaust temperatures and are more effective at NO<sub>x</sub> removal when water vapor is present. *Page 6*



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## Reaping Rewards from 15 Years of Student Competitions

*FutureTruck and other DOE engineering competitions encourage innovations*

The brightly colored vehicles, covered with decals touting their sponsors, raced around the track as the drivers pushed the engines to their limits. To the casual observer, it might appear to be just another day at the California Motor Speedway. However, the vehicles were not race cars — they were experimental sport utility vehicles (SUVs) participating in the FutureTruck 2002 college-level automotive engineering competition.



The competitors were all driving mid-size Ford Explorers that had been modified to incorporate cutting-edge automotive technologies, including fuel cells and other advanced propulsion systems, space-age materials, and such alternative fuels as ethanol and hydrogen. FutureTruck 2002, sponsored by the U.S. Department of Energy (DOE), Ford, and dozens of other industry and agency sponsors, challenged student teams from 15 top North American universities to reengineer a conventional SUV into a low-emissions vehicle with at least 25% higher fuel economy — without sacrificing the performance, utility, safety, and affordability consumers want.

“Most consumers are interested in better gas mileage and helping keep our environment clean, but they also don’t want to have to worry about their own vehicle’s energy consumption and emissions,” says Dr. Harvey Drucker, Associate Director of Energy and Environmental Technology at Argonne. “The overarching goal of FutureTruck and other DOE student competitions is to explore the far boundaries of automotive technology and develop improved vehicles that consumers not only want to drive, but that also don’t guzzle a lot of fuel and generate high levels of harmful emissions.” The emphasis of the competition is on pushing the technology envelope, and this year’s competition saw many successes. For example, 14 out of 15 FutureTruck 2002 vehicles suc-

cessfully operated in at least one event — a record for the first year of a DOE competition in which the teams were working with a new vehicle platform. Another example: the first-place team, the University of Wisconsin–Madison, succeeded in reducing the greenhouse gas impact of the Explorer by 50% and increasing over-the-road fuel economy by 45%. The team reengineered many components and employed advanced materials, such as an aluminum/steel hybrid frame and a titanium exhaust system. Seven out of the ten teams that competed in the over-the-road event achieved better fuel economy than the stock 2002 Ford Explorer, and two teams managed to exceed the stock Explorer’s 1/8-mile acceleration performance.

“The level of reliability in the technologies we’re seeing is very impressive, with the students’ work now meeting or exceeding that of most production vehicles just a few years ago,” explains Bob Larsen, Director of Argonne’s Center for Transportation Research. “The students are often able to use off-the-shelf, near-production-level components — such as electric motors and controllers — in the powertrains, which means their technologies can be quickly implemented in large volume at lower costs.” Larsen also said

that no matter how good the new components and designs are, competitions like FutureTruck are needed to provide a way to test these systems in the field under a wide range of real-life driving conditions.

Argonne’s involvement with Advanced Vehicle Technology Competitions began in 1988 with the Formula SAE challenge, which had engineering students designing, fabricating, and competing with small formula-style race cars. Since then, Argonne has continued to provide technical and organiza-





tional support for a variety of competitions, most involving alternative fuels. The DOE/Argonne involvement with student competitions has also included working with high school students. In the 1994 EV Grand Prix, high school students in the Mid-Atlantic region competed against each other to convert a conventional gasoline-powered car into an electric vehicle. More than 800 students were involved in this project, which combined such diverse educational experiences as auto shop, math, physics, metal shop, journalism, and graphic design.

Over the years, the students' technologies (and the events in which they are tested) have become more and more sophisticated. The teams at FutureTruck 2002 all used advanced hybrid electric design strategies to compete in a series of static and performance events. The events included judging on consumer acceptability, engineering design, acceleration, trailer-towing performance, off-road handling, and on-road fuel economy, as well as on oral presentations. Teams were encouraged to develop technologies that reduced total-energy-cycle greenhouse gas (GHG) emissions. FutureTruck even includes an event that measures upstream fuel-cycle emissions (pollution resulting from producing and delivering a fuel).

The technologies employed in the DOE competitions have led directly to improvements that may soon be implemented by automobile manufacturers. For example, in the 1999 Ethanol Vehicle Challenge, the team from the University of Texas at Austin developed an onboard distillation system that overcame the chronic cold-weather performance problems associated with ethanol's lower volatility and other properties. The design attracted immediate interest from Ford Motor Company. After further testing and refinements, UT Austin and Ford Motor Company were awarded a patent. If system testing and development proceed as hoped, the system could be a standard feature on production vehicles around the middle of this decade.

This example is dramatic proof that the knowledge and effort invested in organizing student competitions to develop alternative fuel technologies can have an impact in the real world. Results like this one also prove that the cooperation of industry, government, and academia is a great approach to keeping North American technology competitive on a global basis. DOE competitions have helped develop thou-

sands of highly skilled engineers with a greater awareness of advanced and "green" automotive technologies and have prepared them to lead the automobile industry in the 21st Century.

Visit the FutureTruck website at [www.futuretruck.org](http://www.futuretruck.org).

### DOE Advanced Vehicle Competitions Organized by Argonne National Laboratory:

Formula SAE	1988 through present
Methanol Marathon	1989
Methanol Challenge	1990
Sunrayce	1990
Solar and Electric 500	1991 through 1994
American Tour de Sol	1991 through present
Natural Gas Vehicle Challenge	1991 through 1993
Atlanta Clean Air Grand Prix	1993 and 1994
Cleveland Electric Formula 500	1994
Hybrid Electric Vehicle Challenge	1993 through 1995
EV Grand Prix	1994
Dash Clean Air Road Rally	1995
Propane Vehicle Challenge	1996 and 1997
FutureCar	1996 through 1999
Ethanol Vehicle Challenge	1999 and 2000
FutureTruck	2000 through present





## Fluid Dynamics Simulations Help Speed Fuel Processor Development

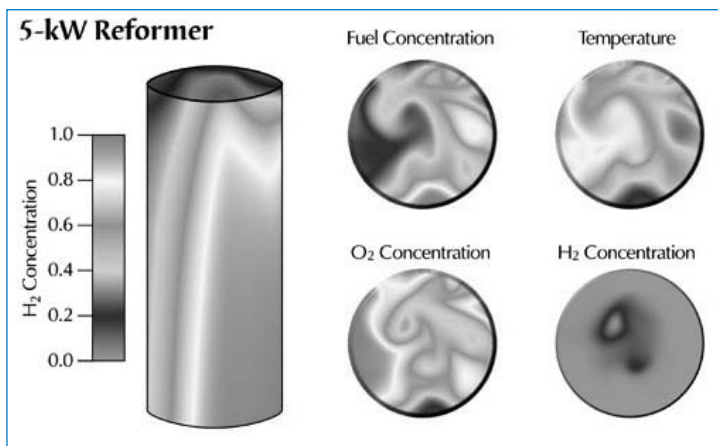
The current excitement over fuel cell-powered passenger cars makes it easy to forget that several crucial components needed for high-volume production of these vehicles do not yet exist. Possibly the most important of these is a production-ready fuel processor that will permit fuel cell-powered cars to run on conventional fuels, rather than on pure hydrogen, making them considerably more attractive to consumers.

Important milestones in fuel processor development have been reached; one of the first came at Argonne with development of the autothermal fuel reforming catalyst, a key component of a fuel reformer that transforms the hydrocarbon molecules in conventional fuels into hydrogen. A recent improvement in the award-winning catalyst allows the reformer to be 25 times smaller than previous models, making it less expensive, less of a drain on fuel economy, and easier to integrate into cars. The technology was transferred to the private sector through a series of cooperative research and development agreements with private companies, including Süd-Chemie Co. and H2fuel, LLC.

Argonne researchers are now working to incorporate the catalytic reformer into an integrated fuel processor that breaks down hydrocarbon fuels into hydrogen and carbon oxides. Undesirable by-products, such as carbon monoxide and sulfur (contained in hydrocarbon fuels), are removed through a series of catalytic reactors, so that the hydrogen stream meets the stringent quality constraints of fuel cells.

The current effort at Argonne is aimed at developing a 5-kW version as a stepping-stone toward a 50-kW model that would be suitable for light-duty vehicles. Design and integration of the fuel processing components are supported by computational fluid dynamics (CFD) simulations that predict three-dimensional fluid flow, mixing, heat transfer, and chemical reactions inside each component of the fuel processor, as well as throughout the entire unit.

Argonne researchers have developed several CFD codes over the years for various applications, including three copyrighted versions for analysis of combustors, multiphase fluid catalytic cracking risers, and glass furnaces integrated with glass melting tanks. To prepare for fuel processor modeling, the researchers modified one of these versions so that simulations could be performed using several computers at the same time. Distributing the workload in a parallel fashion allowed them to greatly increase the number of computational cells in the grids they use in their simulations (from 50,000 to 400,000), providing a much more accurate picture of conditions inside the processor.



*Figure 1. CFD simulation shows large variations in computed fuel and oxygen concentrations and an uneven temperature distribution at the inlet to the catalyst (top of column) caused by inadequate mixing. These nonuniformities cause hydrogen production to fall far short of the theoretical maximum.*

Consumers will undoubtedly demand that fuel cell cars be immediately ready to drive when started. This means that the various zones in the fuel processor must be warmed up very rapidly to their appropriate operating temperatures, so that the hydrogen needed to power the fuel cell is available on demand. CFD simulations are being used to determine fuel processor designs that will enable the reformer to deliver 50-100% of its hydrogen capacity in a very short time (DOE's target for 2005 is 30 seconds). Initial work has also focused on analyzing the impact of incomplete mixing of fuel, steam, and air on hydrogen production in the reformer (Figure 1). This research pointed to the need for an extremely homogeneous feed stream and led to development of a patent-pending mixer design.

Attention has now shifted to modeling the chemical kinetics of the fuel-reforming step. Eventually, CFD simulations will be used in designing the other components and in integrating all of them in an efficient fuel processor. The latter step could prove tricky because the catalysts for the various components have different operating temperatures and different maximum temperatures they can tolerate. Testing the prototype that results from this research program, however, will be easier, thanks to Argonne's Fuel Cell Test Facility, which was established by DOE's Hydrogen Fuel Cell and Infrastructure Technologies Program to provide independent, standardized testing for all types of fuel cell systems in support of fuel cell research.

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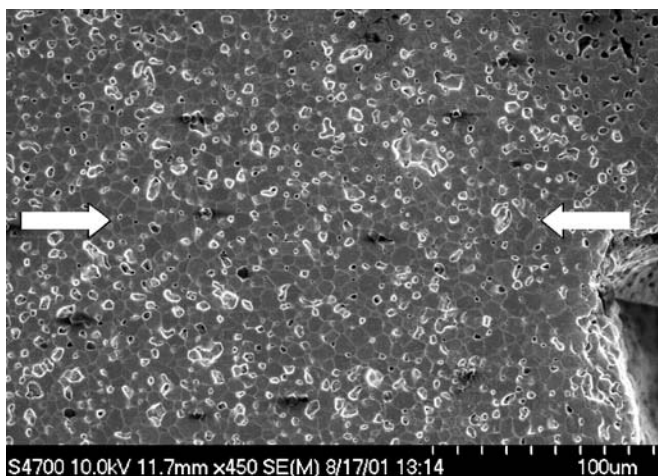
## Power Merger

*Seamlessly bonded ceramics provide new options for optimizing fuel cell electrodes*

For fuel cell electrodes, shape matters. The electrode surface is sculpted with an elaborate pattern of grooves called a flow field. This flow field governs how reactant gases pass through the fuel cell. A good flow field maximizes contact between the gases and the electrode surface, which is where key reactions occur to produce electricity. The power of a fuel cell system is directly related to the surface area available to host the chemical reactions that produce electricity. The design of the flow field is one critical factor in extracting maximum power from a fuel cell unit. However, the use of complex flow fields drives up manufacturing costs, because the electrodes are made of ceramic materials that are difficult to form into complex shapes.

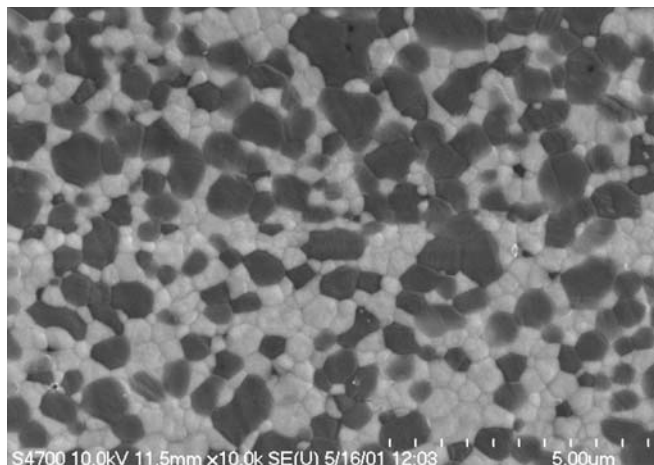
Argonne has demonstrated a new method that could provide a less expensive way to form complex shapes from conductive ceramics. The method forms a strong joint between two ceramic parts while retaining all the electrical properties of the base material. Existing methods of joining ceramics are not suitable for electronic materials.

With the new method, two pieces having different shapes can be layered and then joined directly together (Figure 1). "The key achievement is that the fusion is so complete that the joint disappears, and the electrical properties of the new part are indistinguishable from those of the original material," says Argonne physicist Jules Routbort.



*Figure 1. The image shows the joint after processing. Two pieces of LSM15 have been joined so completely that the joint (arrows) is invisible even to a scanning electron microscope.*

The secret to this transformation is a process called grain-boundary sliding, or GBS. In this process, microparticles of material (grains) migrate between the parts being joined. When the parts are put together and deformed (stretched, compressed, etc.) under particular conditions, the grains



*Figure 2. If conditions are right, the grains of ceramic material slide around each other to form a strong bond. The image shows two different materials chosen to illustrate the grain interpenetration.*

in both samples will slide and rotate, interpenetrating to form a high-strength bond (Figure 2). To visualize this process, picture a commuter train at rush hour. When a crowded train stops at an equally crowded platform, the new passengers must jostle between and around the people already on the train, but eventually everyone finds a place.

Routbort and his colleague Felipe Gutierrez-Mora have demonstrated this joining process with an electronic ceramic called LSM15. This material is a leading candidate for cathodes (air- or oxygen-side electrodes) in high-temperature solid-oxide fuel cells. Samples of LSM15 were heated and then compressed together. Successful bonding took as little as three minutes of compression. The electrical resistivity of the bulk material and the joined material were identical, indicating that the electrical properties of the joint are excellent.

The research team is also exploring several other variations of this method. A further refinement involves using ultrafine powder of the same material as an interlayer, which is sprayed onto the parts to be joined. The team is also testing a method for joining composite materials having slightly different compositions. The comparatively low temperatures make it possible to consider a wider range of ceramics for thermal bonding, and the short times required for joining should make this process commercially viable.

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## New Bifunctional Catalysts Promise Dramatic NO<sub>x</sub> Reductions for Heavy-Duty Diesel Vehicles

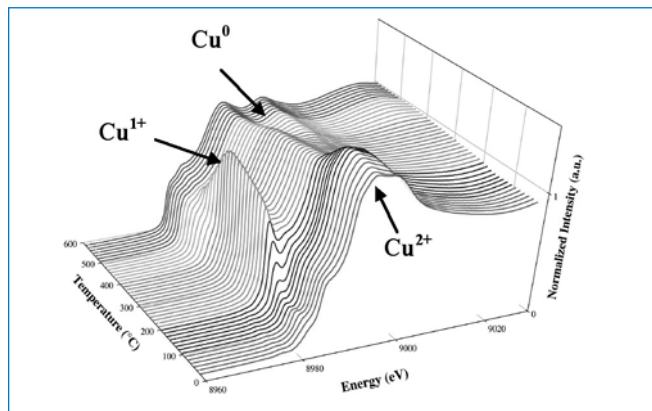
The U.S. Environmental Protection Agency (EPA) typically aims the start date of a new standard toward a point in the future when it projects that the technologies designed to meet the standard will become commercialized. So it was in December 2000, when the agency ruled that a 95% cut in allowed nitrogen oxide (NO<sub>x</sub>) emissions would take effect in 2007 (Figure 1). The exhaust aftertreatment technology to meet that standard does not currently exist. But there is a growing consensus that a technology called “selective catalytic NO<sub>x</sub> reduction” will make an ideal aftertreatment approach if it can be developed and implemented in time.

A number of catalysts have shown promise over the years in systems used to treat diesel exhaust, including the metal-exchanged zeolite Cu-ZSM-5. But the catalysts often lose activity when exposed to the amounts of water vapor typically present in diesel exhaust. They also tend to require temperatures that are too high and produce relatively large amounts of undesired side products, including nitrous oxide (N<sub>2</sub>O) and carbon monoxide (CO).

Argonne researchers recently developed a series of bifunctional catalysts that overcome all of the show-stopping drawbacks of other catalysts. The bifunctional catalysts can operate at diesel exhaust temperatures and are more effective at NO<sub>x</sub> removal when water vapor is present. In addition, NO<sub>x</sub> reduction selectivities under lean-burn conditions range from 95% to nearly 100% and are accompanied by few or no NO<sub>x</sub> side products and virtually no hydrocarbon slippage. Carbon monoxide levels remain higher than the researchers would like, but they have been lowered to about 25% of those obtained using Cu-ZSM-5 alone, and work continues to reduce the amount even more. The researchers’ goal is to develop an efficient NO<sub>x</sub> reduction system that operates pas-



*Figure 1. Truck manufacturers will need new technologies to help them meet EPA regulations that require a 95% cut in allowed NO<sub>x</sub> emissions by 2007.*



*Figure 2. Researchers are using x-ray absorption spectroscopy at Argonne’s Advanced Photon Source to trace the state of copper on Cu-ZSM-5 during H<sub>2</sub> reduction as copper moves from Cu<sup>2+</sup> to a metallic-like state that can be undesirable for NO<sub>x</sub> aftertreatment. Tools such as these are bringing new understanding of the catalyst’s structure and interactions.*

sively, using waste heat and a minimal slipstream of unburned hydrocarbons.

The new catalysts are bimodal, meaning that they consist of two different components: a base metal-exchanged zeolite, such as Cu-ZSM-5, and a special oxide additive. The term “bifunctional” indicates that different types of reactions occur at two different sites. The metal zeolite phase provides the catalytic sites that are responsible for NO<sub>x</sub> reduction, while the additive phase improves oxidation performance and possibly contributes to oxidizing NO to form N<sub>2</sub>O, which is more easily reduced. As a bonus, the additive improves the water stability of the catalyst.

Argonne conducts basic research on the catalysts by using a variety of in situ analytical techniques at the Advanced Photon Source (Figure 2), including infrared (IR) spectroscopy, extended x-ray absorption fine structure (EXAFS), and x-ray absorption near-edge spectroscopy (XANES).

The researchers plan to test the long-term stability of the materials under reaction conditions and evaluate their resistance to the presence of sulfur oxides (SO<sub>x</sub>), which interact with various metals and, together with water vapor, yield sulfuric acid. Argonne’s bifunctional catalysts have attracted the interest of major diesel engine manufacturers and have led to a Cooperative Research and Development Agreement (CRADA) with BP.

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As you can see, Argonne staff have quite a few achievements to boast about in this issue, forcing me to keep my comments here to a minimum. But by now you've probably read my column enough to know what I'm going to say. I've covered the statistics regarding our nation's dependence on foreign oil and the contribution of fossil fuel vehicles to pollution and greenhouse gas emissions in past issues. Now, when energy security is — more than ever — a national priority, I want to reemphasize the importance of the work we're doing here at Argonne, at other national laboratories, and in industry labs and universities across the country to bring advanced vehicle technologies to the road. Our work — from our participation in the DOE student competitions (page 2), to CFD modeling

that will help make a production-ready fuel processor a reality (page 4), to less expensive methods to form conductive ceramics for use in fuel cells (page 5), to bifunctional catalysts for diesel aftertreatment systems (page 6) — will one day lead to massive reductions in air pollution, greenhouse gas emissions, oil spills, and acid rain and to far greater energy security. Please get in touch and find out how we can work together to get there.

Larry R. Johnson  
Director  
ttrdc@anl.gov



A team of Argonne scientists — **Jin Wang, Steve Ciatti, Chris Powell, and Yong Yue** — recently received the 2002 National Laboratory Combustion and Emissions Control R&D Award from DOE's Office of FreedomCAR and Vehicle Technologies for their groundbreaking work in diesel fuel sprays. Their work makes it possible to use x-rays to penetrate gasoline and diesel sprays and reveal how to improve combustion in engines using fuel injector systems.

Seventeen-year-old **Wenyi Cai** was the youngest winner ever of a student poster presentation award at the 11th User Meeting at the Advanced Photon Source. The high school

senior won for her poster titled "Quantitative and Time-Resolved Characterization of Highly Transient Gasoline Sprays by X-Radiography." The poster was based on work Cai did as a student appointee working with staff scientist **Jin Wang**, using the APS and other synchrotron radiation facilities to study gasoline direct-injection sprays.

An article titled "Long-Haul Endurance" in the August 2002 issue of *Mechanical Engineering Magazine* features **Bill Ellingson's** work with heavy-duty truck engine manufacturers to develop improved testing of ceramic components for engines.



Responding to an invitation from Energy Systems' **Michael Wang**, the China Auto Delegation for Fuel Efficiency visited Argonne on August 16th to learn first-hand about Argonne's transportation research program and testing facilities. The group comprises officials from China's State Economy and Trade Commission (SETC) and technical experts from the China Automobile Technology and Research Center (CATARC).

Currently, with the support of the Energy Foundation, CATARC is assisting SETC in developing a package of

vehicle fuel efficiency regulations and policies that could include mandatory light-duty vehicle fuel economy standards, test protocol for measuring vehicle fuel economy, vehicle fuel efficiency labeling and reporting programs, and complementary fiscal policies.

The study tour helped SETC and CATARC to learn (1) the technical approach to developing fuel efficiency standards, (2) the government implementation mechanism for the standards and labeling system enforcement, and (3) technical details for fuel efficiency test procedures.

During the Argonne visit, **Larry Johnson** provided an overview of Argonne's transportation research and development efforts. **Bob Larsen** detailed Argonne's efforts on vehicle emission and fuel economy testing and modeling. **Dan Santini** discussed Argonne's vehicle technology and fuels assessment efforts, the potential of U.S. vehicle fuel economy improvements, and the U.S. and world oil supply and demand situation. **Keith Hardy** and **Steve Ciatti** led the delegation in a tour of Argonne's facilities, including the four-wheel-drive dynamometer for testing hybrid electric vehicle performance and emissions and the locomotive engine laboratory.



Industrial technology development is an important way for the national laboratories to transfer the benefits of publicly funded research to industry to help strengthen the nation's technology base. The stories highlighted in this issue of *TransForum* represent some of the ways Argonne works with the transportation industry to improve processes, create products and markets, and lead the way to cost-effective transportation solutions, which in turn lead to a healthier economic future.

By working with Argonne through various types of cost-sharing arrangements, companies can jump-start their efforts to develop the next generation of transportation technologies without shouldering the often-prohibitive cost of initial R&D alone. Argonne has participated in dozens of these partnerships and has even been involved in helping to launch startup companies based on the products and technologies developed here.

If working with world-class scientists and engineers, having access to state-of-the-art user facilities and resources, and leveraging your company's own capabilities sound like good business opportunities to you, please contact our Office of Technology Transfer and see how we can put our resources to work for you.

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